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Abstract. *The Root Zone Water Quality Model (RZWQM, V 3.25) was used to simulate the effect of swine manure applications on nitrate-nitrogen (NO_3-N) concentrations in subsurface drain water from continuous corn for Iowa soils. Measured values of subsurface drain flow, NO_3-N concentrations in drainage water, and residual NO_3-N in the soil profile from three chisel plow plots were available for the growing seasons of 1993 and 1995. The measured values were used to evaluate the RZWQM. Several parameters of RZWQM were calibrated to provide satisfactory subsurface drain flow, nitrate in drainage water and nitrate in soil profile for the growing season of 1993. The calibrated parameters were then used to simulate subsurface drain flows, its NO_3-N concentrations, and residual NO_3-N content in the soil profile as affected by manure application for the growing season of 1995. Simulated subsurface drain flows, NO_3-N concentrations, and total residual NO_3-N contents were compared with the measured values. Predicted daily subsurface drain flows by the RZWQM were close to the observed flows. Annual total subsurface drain flows predicted by the model were also close to the observed values (difference over two years was –3.9%). The predicted NO_3-N concentrations in subsurface drainage water followed the observed trends well for years 1993 and 1995 for all three plots. The annual average NO_3-N concentrations predicted by the RZWQM were also in close agreement with the measured values for 1993 and 1995 (within a difference of –3.0%). Linear regression (zero interception) between the predicted values for the pooled data (average of three plots for two years) and the measured data gave an R^2 value of 0.88 with a slope of 0.96. The predicted soil NO_3-N contents in 0-1.2 m soil profile were also in close agreement with the measured values in the field. The overall results of this study indicate that RZWQM is capable of simulating various rate of manure applications in different weather and soil conditions.* ***Keywords.*** *Hydrology, Water quality, Swine manure, Subsurface drainage.*

Manure is a valuable source of nutrients and soil amendment that improves the physical condition of the soil for plant growth and increases the organic matter content of soil (Freeze and Sommerfeldt, 1985; Campbell et al., 1986; Sommerfeldt et al., 1988). However, excessive amounts of manure application on agricultural land can be a potential source of pollution for groundwater and surface water bodies. The amount of nitrate-nitrogen (NO_3-N) found in groundwater has been linked to the amount of nitrogen (N) applied to crops (Hallberg, 1986). Environmental concerns resulting from excessive manure applications have prompted researchers to investigate the fate and transport of manure-nutrients in agricultural fields. A few studies have been conducted in the USA and Canada to study the impact of swine manure on surface and groundwater contamination (Angle et al., 1993; Hubbard et al., 1987; Kanwar et al., 1995, 1996).

Mathematical models have been developed to evaluate the environmental impact of various manure management practices under field conditions. These models can be used as inexpensive and time saving tools to predict the effects of various Best Management Practices (BMPs) on the environment. Jabro et al. (1993) evaluated the LEACHM (Hutson and Wagenet, 1992) and the NCSWAP (Molina and Richards, 1984) models for predicting NO_3-N leaching losses below the 1.2 m depth from N-fertilized and manured corn lysimeters. They reported that neither model predicted nitrate leaching successfully for most of the treatments for validation years with LEACHM statistically performing better than the NCSWAP model. Yoon et al. (1994) and Minkara et al. (1995) used the GLEAMS (Knisel et al., 1992) to predict nitrate and ammonium losses in surface and subsurface runoff from poultry litter applications. Large differences between observed and predicted data were reported for all manure application rates and experimental sites.

The RZWQM (Root Zone Water Quality Model) is a field scale research model developed by the USDA-ARS (1992). The RZWQM has state-of-the-science flow and nutrient and chemical processes that simulate the effects of various agricultural management practices on water quality. The RZWQM is still under testing and validation for various climatic and management conditions. Although several modules of the RZWQM have been tested and validated for various soil types and management practices (Ahuja et al., 1993, 1995; Ma et al., 1996; Azavedo et al.,

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1997), very few studies have been conducted to evaluate the manure component of the RZWQM under field conditions. The objective of this study was to evaluate the RZWQM (Root Zone Water Quality Model, V. 3.25) for predicting NO_3-N concentrations in subsurface drain flows as affected by swine manure applications. Two years (1993 and 1995) of field data on NO_3-N concentrations in subsurface drain flows and total NO_3-N in 0-1.2 m soil profile from three chisel plow plots, which received liquid swine manure, were used to evaluate the RZWQM.

DESCRIPTION OF RZWQM (VER. 3.25)

RZWQM is a physically based model that incorporates the important physical, chemical, biological, physiological, and management processes of an agricultural crop system. RZWQM consists of water, chemical, and heat transport modules; a plant growth module; an evapotranspiration module; a chemistry module; an organic matter/nitrogen cycling module; a pesticide module; and a management practices module. Some of these modules are still in the process of validation under field conditions. A detailed discussion on these modules can be found in the RZWQM technical documentation (USDA-ARS, 1992) and RZWQM's user manual (RZWQM Team, 1995). The following paragraphs give a brief description of hydrologic, nutrient, and management practices components (not necessarily in that order).

WATER AND CHEMICAL TRANSPORT

The water flow and chemical transport processes in RZWQM are divided into two phases: (1) infiltration into soil matrix and macropores and macropore-matrix interactions during a rainfall or irrigation; and (2) redistribution of water and chemicals following infiltration. A modified form of Green-Ampt equation is used to calculate infiltration (Ahuja et al., 1995). The excess rainfall, which is the difference between rainfall and infiltration during each time step, is designated as overland flow or runoff. Redistribution of water and chemicals between rainfall or irrigation events is modeled by Richard's equation. Root water uptake is estimated by using the method given by Nimah and Hanks (1973).

Subsurface drainage rate is calculated from Hooghoudt's steady-state equation (Bouwer and van Schilfgaarde, 1963) as applied by Skaggs (1978). This equation is intended to correct for the 2-D effects of subsurface drainage by estimating the flux at the center point between two parallel drains. The RZWQM requires knowledge of depth to drain, drain spacing, and effective drain radius to calculate the drainage rate. The calculated drainage rate is satisfied either through a point sink term in the Richard's equation for redistribution, or drainage through a distributed sink extending from the top of water table to two soil layers below the subsurface drain. Thus, the depth of water table estimated by the model is given at the midpoint between drains.

Nitrate is treated as a conservative chemical with an adsorption constant (K_d) value of zero. Prior to infiltration, nitrate concentrations in the mobile (mesopores) and immobile (micropores) waters are assumed to be in equilibrium. During infiltration, only about 50% or less of the mesopores are assumed to be piston-displaced followed by an instantaneous mixing of solution in the mesopores. At the end of infiltration, water and nitrate in the meso- and micropores are allowed to equilibrate. Nitrate is transported with water from layer to layer. Nitrate concentrations in the drainage water are estimated as a function of nitrate concentrations in the saturated layers of the soil profile.

EVAPOTRANSPIRATION AND PLANT GROWTH COMPONENTS

The detailed description of the evapotranspiration (ET) subroutine in the RZWQM has been given by Farahani and Bausch (1995). A closed form solution of the Penman Montieth equation (Shuttleworth and Wallace, 1985) is used to calculate potential evapotranspiration. Actual evapotranspiration incorporates stomatal resistance and soil resistance as a function of soil water conditions. The original formulation of the model was modified to incorporate the effects of residue on evaporation from bare soil and crop transpiration on a daily basis.

RZWQM uses a generic plant growth model to simulate growth of several important crops under various environmental and management practices. Plant growth is divided into 5 phenological growth stages: (1) germination; (2) emergence; (3) 4-leaf stage; (4) vegetative growth; and (5) reproductive stage. Nitrogen becomes available to the plant via the water taken up by transpiration, i.e., passive N-uptake. If the amount of N-uptake through water taken up by the plant is inadequate to meet plant demand, then active N-uptake occurs. Carbon dioxide is assimilated by the plant at a rate dependent on light intensity, canopy structure, and the current environmental fitness, and carbohydrate is partitioned between leaves, stems, roots, and reproductive organs.

NUTRIENT COMPONENT

The nutrient sub-model organic matter/nitrogen cycling (OMNI) of RZWQM is a state-of-the-art model for carbon and nitrogen cycling in soil systems. A detailed description of the nutrient model is given in the Technical Documentation of RZWQM (USDA-ARS, 1992). Organic matter (OM) is distributed over five computational pools and is decomposed by three microbial biomass populations. These pools are fast and slow incorporated soil residue pools (relatively unimportant in no-till practice), and fast and medium (representing potentially mineralizable N) and slow soil humus pools.

OMNI simulates all the major pathways including mineralization-immobilization of crop residues, manure, and other organic wastes; mineralization of the soil humus fractions; inter-pool transfers of carbon and nitrogen; denitrification (production of N_2 and N_2O); gaseous loss of ammonia (NH_3); nitrification of ammonium to produce nitrate-N; production and consumption of methane gas (CH_4) and carbon dioxide (CO_2), and microbial biomass growth and death. In this sub model (OMNI), growth and subsequent death of microorganisms drive most of the processes and are a function of environmental variables such as soil temperature and water content, soil pH, soil oxygen levels, and solution concentrations of nutrients.

AGRICULTURAL MANAGEMENT PRACTICES

Organic wastes (manure and its associated beddings) are treated as residues and partitioned into slow and fast residue pools (Ma et al., 1997), whereas the amount of ammonium in the manure is added into the NH_4 pool directly. The management sub-model consists of a description of management activities influencing the state of the root zone. The management sub-model of RZWQM includes typical tillage practices for most common crop rotations and the impact of these tillage practices on surface roughness, soil bulk density, and micro and macro porosity. The timing of typical management practices such as fertilizer and pesticide applications, irrigation, planting, primary tillage cultivation, and harvest operations are functions of soil water conditions. The algorithms used for tillage-induced bulk density changes and residue incorporation are adopted and modified from the USDA-Water Erosion Prediction Project (WEPP) model (Laflen et al., 1991). Soil reconsolidation after tillage, rainfall or irrigation are also simulated in the model.

MATERIALS AND METHODS

FIELD EXPERIMENTAL DESIGN AND OBSERVED DATA

The experimental site for this study was located at Iowa State University's Northeast Research Center near Nashua, Iowa. The experimental plots are located on a predominantly Kenyon loam (fine-loamy, mixed, mesic, Typic Hapludoll) soil with 3 to 4% organic matter. Table 1 shows the selected soil properties for the study site. Pre-Illinoian glacial till overlies a carbonate aquifer used for water supply. However, in some areas, bedrock is near the surface. These soils have seasonally high water tables and benefit from subsurface drainage. The study site has 36, 0.4-ha experimental plots with fully documented tillage and cropping records for the past 17 years. Each plot is drained by a single subsurface drain line installed at the 1.2 m depth. The drains are spaced at 28.5 m apart. In 1988, these drain lines were intercepted by individual sumps to study water quality and quantity issues related to subsurface drainage. Detailed information on the drainage system at the Nashua site is available from Kanwar et al. (1993).

A field study was initiated in 1993 to investigate NO_3-N leaching losses to subsurface drainage water as affected by swine manure application for two cropping systems [continuous-corn (CC) and corn-soybean (CS) rotation] under chisel plow. The NO_3-N losses from manure plots were compared with losses from plots with inorganic fertilizer. Swine manure was obtained from a manure pit under a growing/finishing facility building. Swine manure was applied uniformly for every growing season in the late fall of previous year. Applying proper amounts of swine manure to reach target nitrogen levels was difficult.

Fall 1992 rates of 32 736 L/ha (giving equivalent to 112 Kg/ha) for CS and 37 412 L/ha (135 Kg/ha) for CC were applied based on published nutrient values of swine manure. It was assumed that all ammonia and 50% of the organic nitrogen would be available for crop use for the first year. Therefore, based on total nitrogen and ammonia nitrogen available in 1 L of manure, manure application rates (L/ha) were calculated. The chemical composition of the applied manure is given in table 2. Analysis of applied manure indicated that only 81 kg-N/ha and 84 kg-N/ha were applied when target values were 112 and 135 kg-N/ha. Manure application in the fall of 1993 was increased to 67 343 L/ha for CP and 79 500 L/ha for CC based on a manure sample collected from an agitated manure pit approximately one month prior to application. However, analysis of applied manure showed that

Table 1. Selected soil properties for Kenyon, Floyd, and Readlyn soil as a function of horizons, used as input for RZWQM simulations*

Horizon No.	Depth (m)	Bulk Density (Mg/m^3)	Porosity (m^3/m^3)	Particle Size Dist (%) Sand	Silt	Clay
Kenyon Soil						
1	0.0-0.20	1.36	0.49	38	42	20
2	0.20-0.41	1.53	0.43	41	34	25
3	0.41-0.50	1.55	0.42	42	32	26
4	0.50-0.69	1.60	0.40	43	30	27
5	0.69-0.89	1.65	0.38	44	28	28
6	0.89-1.23	1.70	0.36	44	31	25
7	1.23-1.67	1.75	0.34	44	31	25
8	1.67-2.52	1.75	0.34	44	31	25
Floyd Soil						
1	0.0-0.43	1.29	0.51	30	44	26
2	0.43-0.58	1.40	0.47	33	42	26
3	0.58-0.85	1.45	0.45	54	22	24
4	0.85-1.15	1.58	0.40	47	29	24
5	1.15-1.40	1.70	0.36	35	40	25
6	1.40-1.53	1.70	0.36	35	40	25
7	1.53-2.52	1.75	0.36	35	40	25
Readlyn Soil						
1	0.0-0.20	1.34	0.49	31	43	26
2	0.20-0.30	1.45	0.45	31	43	26
3	0.30-0.43	1.45	0.45	37	38	25
4	0.43-0.54	1.50	0.43	37	38	25
5	0.54-0.68	1.60	0.40	55	24	21
6	0.68-0.89	1.65	0.38	46	28	26
7	0.89-1.10	1.70	0.36	46	28	26
8	1.10-1.50	1.70	0.36	46	28	26
9	1.50-2.52	1.70	0.36	46	28	26

*Adopted from Singh et al. (1996).

Table 2. Chemical composition of the manure applied in 1993, 1994, and 1995

Year	Chemical Parameters: Total Nitrogen (TKN) (mg/L as N)	Ammonia (mg/L as N)	Total P (mg/L as P)	Potassium (mg/L as K)	Solids (%)
1993	4907.5	277.3	1900.0	2100.0	6.4
1994	3470.0	258.0	nd*	nd	nd
1995	6288.0	nd	2565.8	2858.2	8.2

* No data was available.

Table 3. Dates of tillage, planting, manure application, and harvesting for 1993, 1994, and 1995

Day of Year: 1993*	1994	1995	Activity
15 Nov	12 Nov	17 Nov.	Fall application of manure
20 Nov	17 Nov	22 Nov	Primary tillage (chisel plow)
17 May	2 May	15 May	Corn planting
21 July	2 June	14 June	Corn cultivation
1 Sept	2 Sept	7 Sept	Approximate maturity
25 Oct	28 Sept	22 Sept	Corn harvesting

* Application of manure for 1993 was applied in fall of 1992. For 1994 and 1995, applications were made in the fall of 1993 and 1994, respectively.

application rates were two to three times greater than target levels. Manure application rates in the fall of 1994 were based on average nutrient values of manure applied in the two previous years. Dates for farming operations and other activities are given in table 3.

Subsurface drain water samples were collected three times a week for NO_3-N analysis. Soil samples were also collected three to four times a year for analyzing residual NO_3-N. Measured data on NO_3-N concentrations in subsurface drain water and residual soil profile NO_3-N for 1993 and 1995 from three chisel plow plots (22, 35, and 13) which received manure and were under the continuous-corn system were used for model calibration and validation.

Model Input Needs

Climatic Data. The model requires daily input values of air temperature (min and max), wind speed, short wave radiation, and relative humidity. All the daily climatic data needed for model simulations for the study site were available except wind speed and pan evaporation. Wind speed and pan evaporation data collected at a nearby site were used for the simulations.

Breakpoint rainfall data are required as model inputs. If a given rainfall event is plotted as cumulative rainfall vs. time, each point where there is a substantial change in slope (representing a change in rainfall intensity) will represent a breakpoint. For the simulations for 1993, 1994, and 1995, rainfall data recorded by data loggers at the experimental site were used. Data loggers provide direct breakpoint data. For missing data, daily rainfall data collected at the site by non-recording rain gages were used to estimate breakpoint data. Total rainfall for 1993, 1994, and 1995 were 1026, 751, and 802 mm, respectively.

Soil Physical Parameters. A 2.52-m deep soil profile was considered for model simulations. This soil profile was divided into seven or nine horizons depending on the type of soil (USDA-SCS, 1982). For each horizon, soil bulk density, porosity (estimated by bulk density and particle density), and particle-size distribution were used as inputs to the model. Measured values of bulk densities for surface horizon and particle-size distribution for all the horizons were adopted from Singh (1994). Bulk densities for the remaining horizons were taken from Sharpley and Williams (1990). Among soil hydraulic properties, only soil water content at 33 kPa suction (Θ_{33kPa}) for each soil horizon was taken from Sharpley and Williams (1990). All other hydraulic properties, such as saturated/unsaturated hydraulic conductivity, effective porosity, and bubbling pressure, were estimated by the RZWQM based on bulk density, Θ_{33kPa}, and texture data.

Crop Growth Data. RZWQM uses a generic crop growth model to simulate plant growth. Default values for various plant growth parameters as recommended in the RZWQM's user manual were used. Planting and harvesting days, number of plantings, planting depth, planting density, harvesting efficiency, etc., are required as input to the model and were collected at the research site.

Tillage and Chemical Management Data. RZWQM needs tillage-related information to simulate tillage effects on soil properties (bulk density, macroporosity, hydraulic properties, and residue incorporation). Tillage and planting activities were carried out on the field each year as soon as soil conditions were appropriate for these operations. Tillage consisted of a chisel plow operation each year. Continuous corn plots received nitrogen application through swine manure. Actual application rates of various nutrients applied through swine manure in each year are given in table 4.

Table 4. Actual N, P, K from swine manure applications for continuous corn plots for 1993, 1994, and 1995

Application Rate	1993	1994	1995
N (kg/ha)	81.8	280.0	501.8
P (as P_2O_5) (kg/ha)	160.2	459.2	156.8
K (as K_2O) (kg/ha)	85.1	342.7	154.6

Model Evaluation

The evaluation procedure included both model calibration and validation processes. The input parameter values required for model simulations were obtained either from direct field measurements and literature sources (default model values) or through a calibration process where selected model parameters were adjusted within an expected range and the discrepancies between measured and predicted values were minimized. The model calibration process focused mainly on input parameters controlling subsurface drain flows and their nitrate concentrations. The RZWQM was calibrated for the site conditions using the growing season data of 1993. Initial calibration focused on the soil water parameters related to subsurface drainage. Lateral saturated hydraulic conductivity (LK_{sat}) and effective porosity (EP) were two main parameters which affect subsurface drain flows most (Singh et al., 1996). LK_{sat} affected the peak subsurface drain flows while the EP affected the entire shape of the subsurface drain flow hydrograph. First, EP was calibrated to match the observed and predicted subsurface hydrographs and then LK_{sat} was calibrated to adjust the peak subsurface drain flows and total subsurface drain flow volume. The criterion used for model calibration was to minimize the differences between predicted and observed total subsurface drain flow for 1993. Initial soil water contents were kept at field capacity in the beginning of the simulations but adjusted later to make sure that the model predicted the drain flows on the same day they were observed in the field.

The calibration for nutrient and chemical parameters followed after the hydrology parameters were calibrated. Various rate constants (rate constants for nitrification, denitrification) were calibrated using the observed NO_3-N data for 1993. The major criterion to calibrate various input parameters for nutrient component of the model was to minimize the difference between observed and predicted annual average NO_3-N concentrations in the subsurface drain flows. A list of calibrated parameters for both hydrology and nutrient components is given in table 5.

After the model was calibrated for the 1993 year, it was evaluated using 1995 subsurface drain flow, NO_3-N concentrations and total soil profile NO3-N data. The model evaluation included both graphical display of observed and predicted data and also a statistical

Table 5. A list of calibrated hydrological, nutrient, and plant growth parameters

Description of Parameter	Calibrated Value
Hydrologic Parameters	
Plot # 22	
LK_{sat} (mm/h)*	3.0
DP (m^3/m^3)†	0.17
Plot # 35	
LK_{sat} (mm/h)	3.2
DP (m^3/m^3)	0.15
Plot # 13	
LK_{sat} (mm/h)	3.2
DP (m^3/m^3)	0.18
Nutrient and Plant Growth Parameters	
Maximum N uptake rate (g/plant/day)	2.0
Amount of biomass needed to obtain leaf area index of 1.0 (g)	10.0
Normal max. root system depth (m)	2.0
Coefficient of Ahrenius equation for denitrification	1.0E+12
Coefficient for Ahrenius o.m. decay equations for:	
a Fast decaying soil o.m.	2.5E-07
b Medium decaying soil o.m.	5.0E-08
c Slow decaying soil o.m.	4.5E-10

* Lateral saturated hydraulic conductivity.
† Drainable porosity.

Table 6. Total annual predicted and observed subsurface drain flows for 1993 and 1995*

Year	Rainfall (mm)		Subsurface Drain Flows (mm) Plot No. 22	Plot No. 35	Plot No. 13	Average†
1993	1026	Observed	378.0	339.0	451.0	389.0
		Predicted	399.0	339.0	464.0	401.0
		% Difference	+5.6	0.0	+2.9	+3.1
1995	802	Observed	97.0	108.0	151.0	119.0
		Predicted	91.0	99.0	127.0	106.0
		% Difference	–6.2	–8.3	–15.6	–10.9

* Simulations were not conducted for 1994.
† Average of three plots.

comparison between predicted and observed NO_3-N concentrations in subsurface drain water and total soil profile NO_3-N contents. The percentage difference between observed and predicted data was calculated as [(predicted – observed) / observed] $\times$ 100.

Results and Discussion

Two years (1993 and 1995) of field data from manured plots were used to evaluate the RZWQM simulations in predicting NO_3-N concentrations in the subsurface drain water and residual soil profile NO_3-N contents. Data from the year 1994 were not used in this study because 1994, being a dry year, resulted in too few data points for model testing. The model simulations included both model calibration and evaluation. After calibrating the model for the year 1993, the model was evaluated by using the field data from the year 1995. Simulations were conducted from Day 1 through Day 365 (1 January to 31 December) of each year.

Subsurface Drain Flows

Cumulative predicted and measured subsurface drain flows for the calibration year 1993 are presented in table 6. As shown in table 6, the cumulative predicted flows for all three plots were within 5.6% of observed flows. Overall average for all three plots showed that predicted annual subsurface drain flow was 3.1% higher than observed average flow.

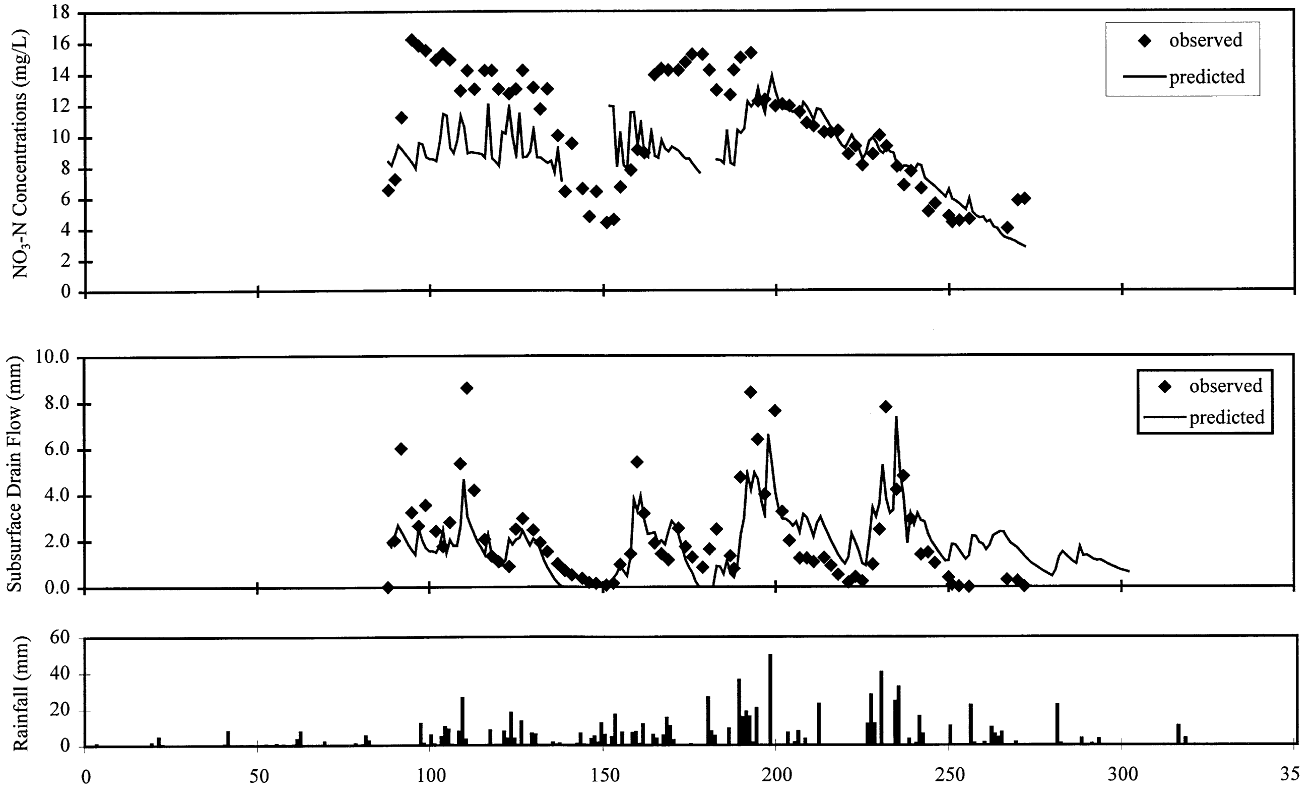
Figures 1, 2, and 3 show the daily simulated and observed subsurface drain flows for the calibration year 1993 for plots 22, 35, and 13, respectively. Simulated subsurface drain flows for all three plots followed the observed trend reasonably well (figs. 1, 2, and 3). Although the model slightly underpredicted peak subsurface drain flows in the beginning of the growing season (April), simulated peak subsurface drain flows were close to the observed flows for the later part of the growing season. This could be due to the fact that model does not take into account the accumulated snow on the surface in the beginning of the season. This snow could melt and will make a large portion of the observed subsurface drain flows. Also, the model tends to slightly overpredict the surface drain flows for the months of September and October. The reason for this could be attributed to the underprediction of evapotranspiration. Overall, the simulated subsurface drain flows for all three plots for the calibration year 1993 matched the observed flows really well with few exceptions (figs. 1, 2, and 3; table 6).

The model evaluation was performed by comparing the measured subsurface drain flows for the year 1995 with the predicted data. Cumulative simulated subsurface drain flows for 1995 compared reasonably well with the measured flows for all three plots (overall percentage difference = –10.9%). Although model predictions for plots 22 and 35 were within 10% of observed values, the model underpredicted the flows by 15.8% for the plot 35.

Daily simulated and measured subsurface drain flows for all three plots for 1995 compared well (figs. 4, 5, and 6). Observed and predicted values of subsurface drain flows compared well, although peak subsurface drain flows were usually underpredicted. The year 1995 was a relatively normal rainfall year and both predicted and measured subsurface drain flow data did not show many high peaks. Although there were some discrepancies, the overall timings and amounts of flows were close to the observed values. The discrepancies in predictions could be due to spatial variability, inaccurate estimation of macropore flow, and also due to human errors involved in measuring data. Approximate estimation of break point rainfall data for missing values could also result in discrepancies between predicted and measured subsurface drain flows.

NO_3-N Concentrations in Subsurface Drain Water

Besides model parameters, initial values of microbial populations and organic matter pools are also important in predicting NO_3-N concentrations in subsurface drain water and the soil profile. Default values based on guidelines in the RZWQM manual (RZWQM Team 1995) were used for initial biomass population and organic matter pools. The



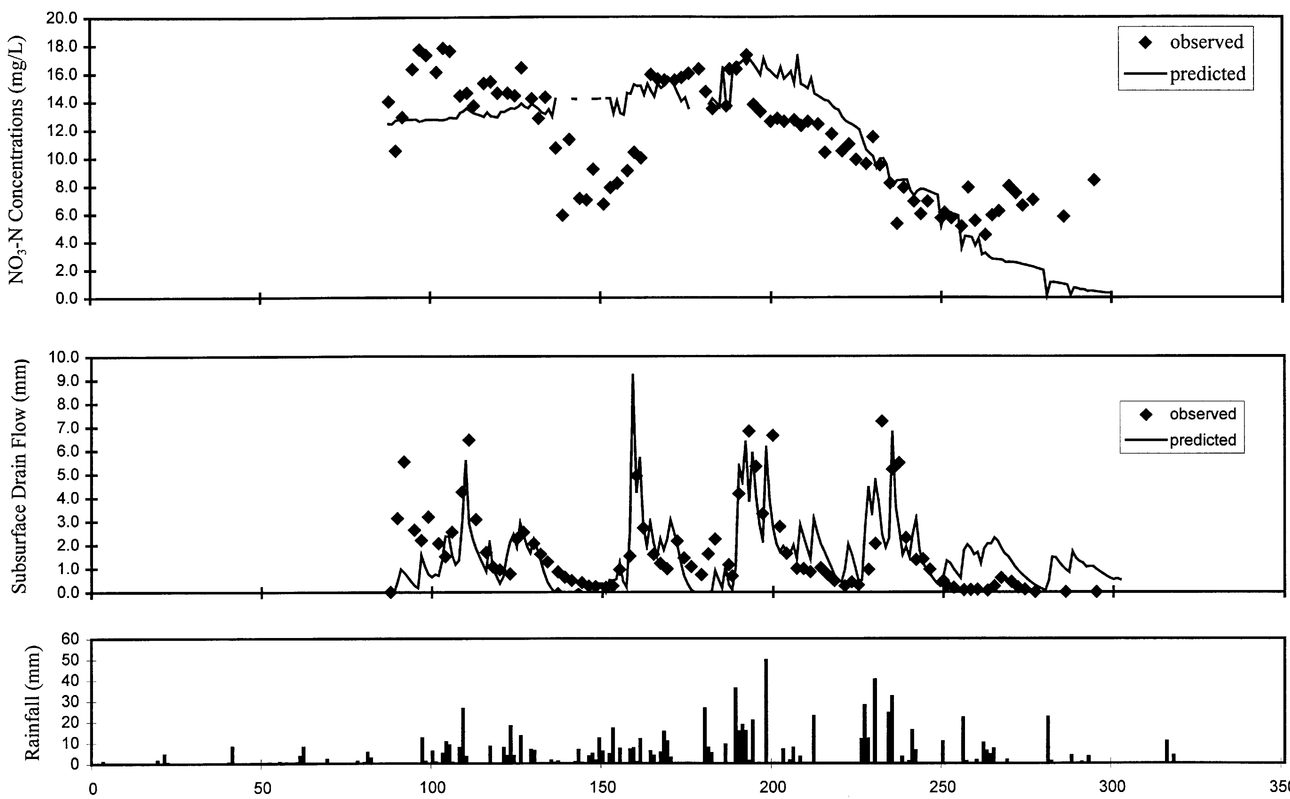


Figure 2–Daily observed and predicted subsurface drain flow and its NO_3-N concentrations for continuous corn plot (no. 35) for the year 1993.

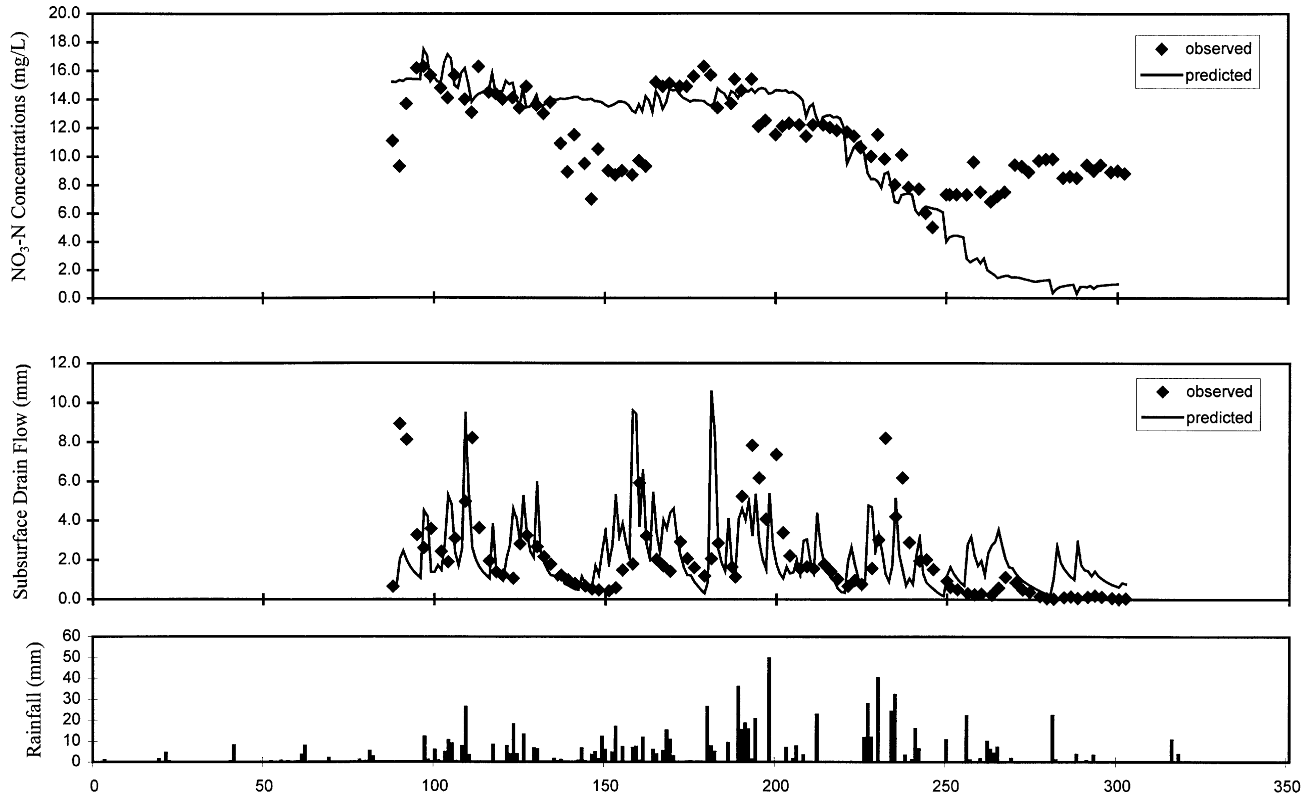


Figure 3–Daily observed and predicted subsurface drain flow and its NO_3-N concentrations for continuous corn plot (no. 13) for the year 1993.

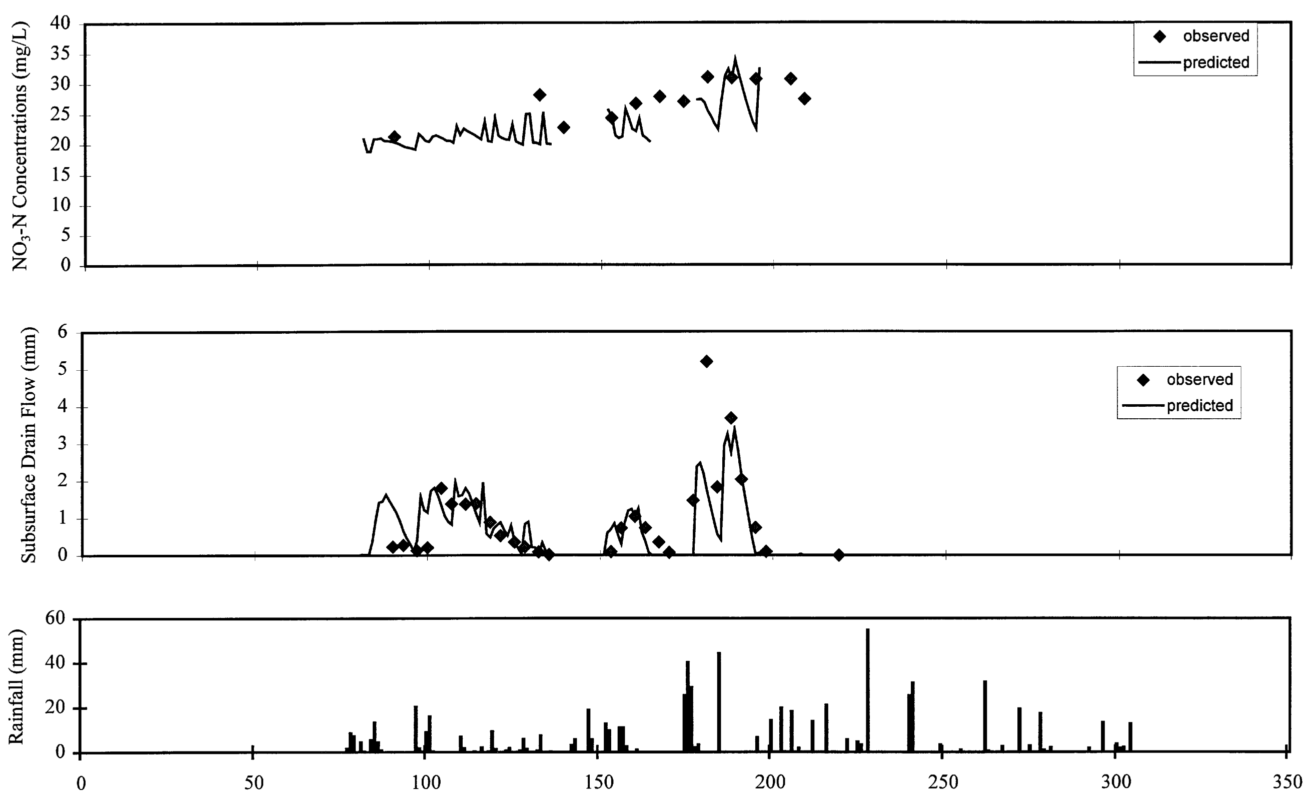


Figure 4–Daily observed and predicted subsurface drain flow and its NO_3-N concentrations for continuous corn plot (no. 22) for the year 1995.

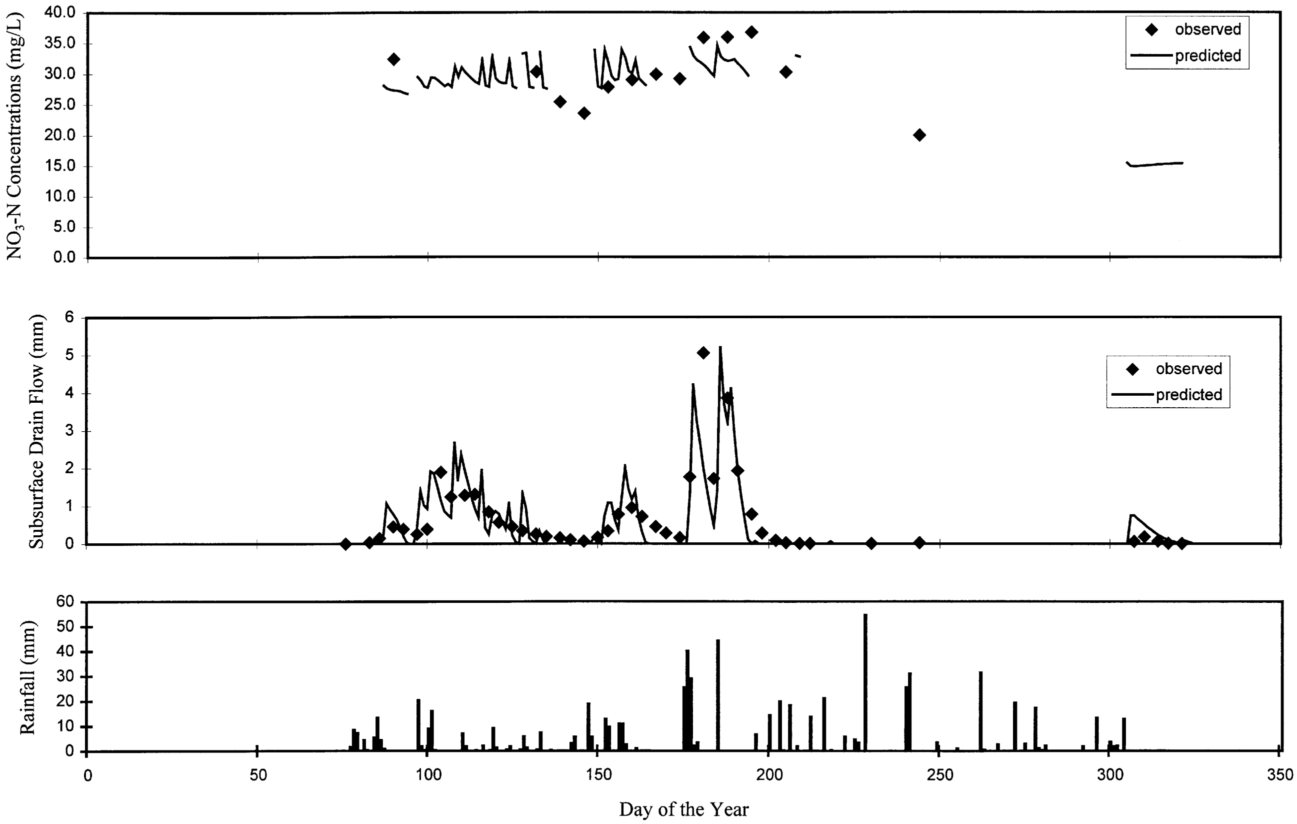


Figure 5–Daily observed and predicted subsurface drain flow and its NO_3-N concentrations for continuous corn plot (no. 35) for the year 1995.

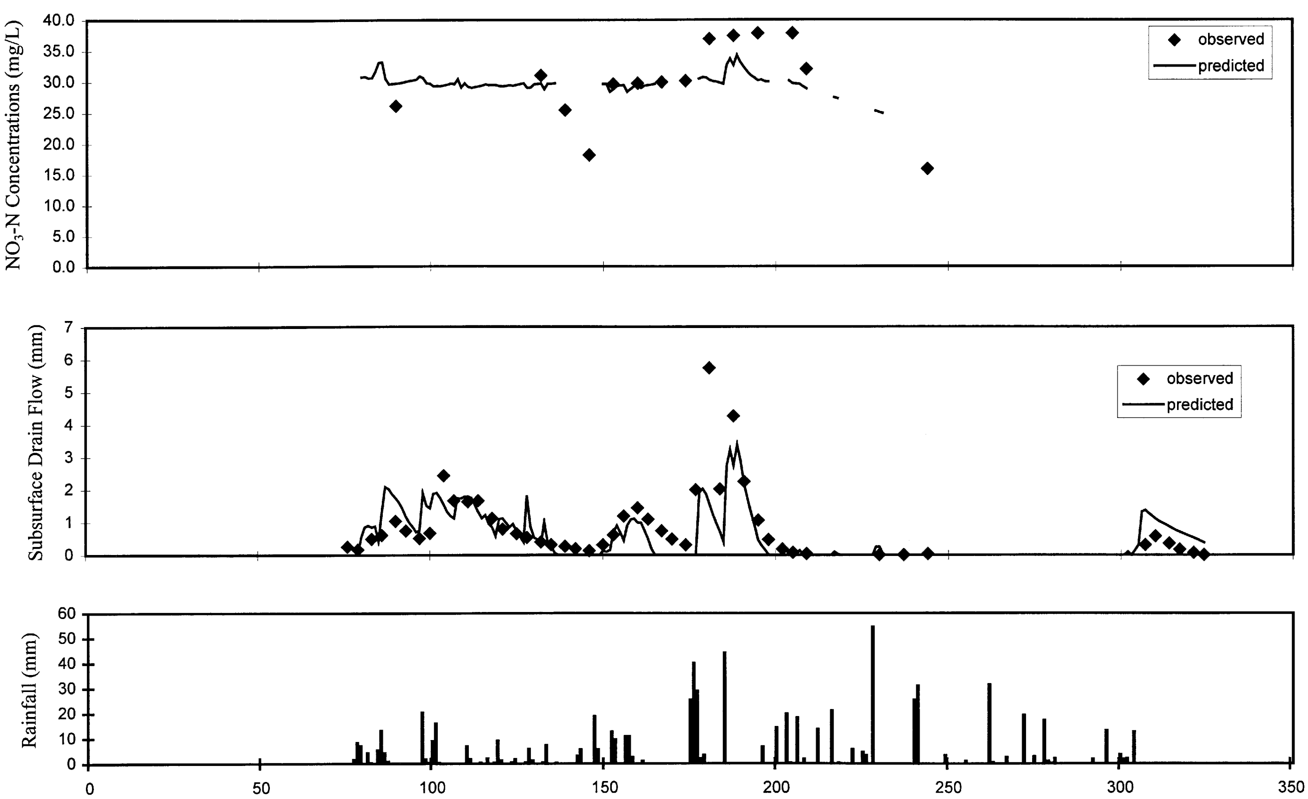


Figure 6–Daily observed and predicted subsurface drain flow and its NO_3-N concentrations for continuous corn plot (no. 13) for the year 1995.

Table 7. Average annual predicted and observed NO_3-N concentrations in subsurface drain flows for 1993 and 1995†

Year	Rainfall (mm)		Plot No. 22	Plot No. 35	Plot No. 13	Average†
			NO_3-N Concentrations (mg/L)			
1993	1026	Observed	10.5	11.4	11.3	11.1
		Predicted	10.2	11.9	10.5	10.9
		% Difference	+2.9	+4.4	–7.1	–1.8
1995	802	Observed	25.1	31.9	29.8	28.9
		Predicted	25.8	29.9	27.4	27.7
		% Difference	+2.8	–6.3	–8.1	–4.2

* Simulations were not conducted for 1994.
† Average of three plots.

transfer coefficients between organic matter pools are also very vital to calculate correct nitrogen cycle.

Annual NO_3-N concentrations in subsurface drain flows were calculated by computing the flow weighted averages of the concentrations over the entire growing season. Annual measured NO_3-N concentrations in subsurface drain water were close to the nitrate concentrations predicted by the RZWQM for 1993 (calibration year) and 1995 (table 7). For 1993, predicted NO_3-N concentrations (annual average) were within –1.8% of measured concentrations, while for 1995, model predicted concentrations were within –4.2% of the measured values. Model predictions of daily NO_3-N concentrations in subsurface drain water followed the observed trend reasonably well for 1993 (figs. 1, 2, and 3). The model predicted the NO_3-N concentrations very accurately for the entire growing season for plot 22 except in the end when concentrations were slightly underpredicted (fig. 1). Similar behavior of NO_3-N concentration predictions for the other two plots (35 and 13) was observed (figs. 2 and 3). Although model predictions were close to the observed values for all three plots in 1993, the model underpredicted NO_3-N concentrations in subsurface drain water at the end of the growing season.

The model underpredicted NO_3-N concentrations for plot 35 and 13 for 1995, while overpredicting for plot 22 (table 7). The NO_3-N concentrations in subsurface drain water for 1995 were greater than 1993. There were two reasons for this: (1) year 1994 being a dry year, not much leaching of NO_3-N occurred during that year so NO_3-N accumulated in the soil profile and became available for leaching during 1995 season; and (2) a higher amount of N was applied with manure in 1995 compared to 1993. A close look at the figures 4, 5, and 6 will reveal that very few water samples were collected for chemical analysis due to low flow conditions around the end of growing season. The decreasing model predictions of NO_3-N concentrations for 1995 show that the model is capable of simulating the effect of manure applications on groundwater quality.

Figure 7 shows the 1:1 and best fit line for observed and predicted NO_3-N concentration in subsurface drainage water data (pooled data). Considering the average for all three plots for two years of simulation (fig. 7), it can be concluded that RZWQM does a good job in simulating the effects of manure applications on subsurface drain water quality for Iowa soils (R^2 = 0.88). The slope of the best line

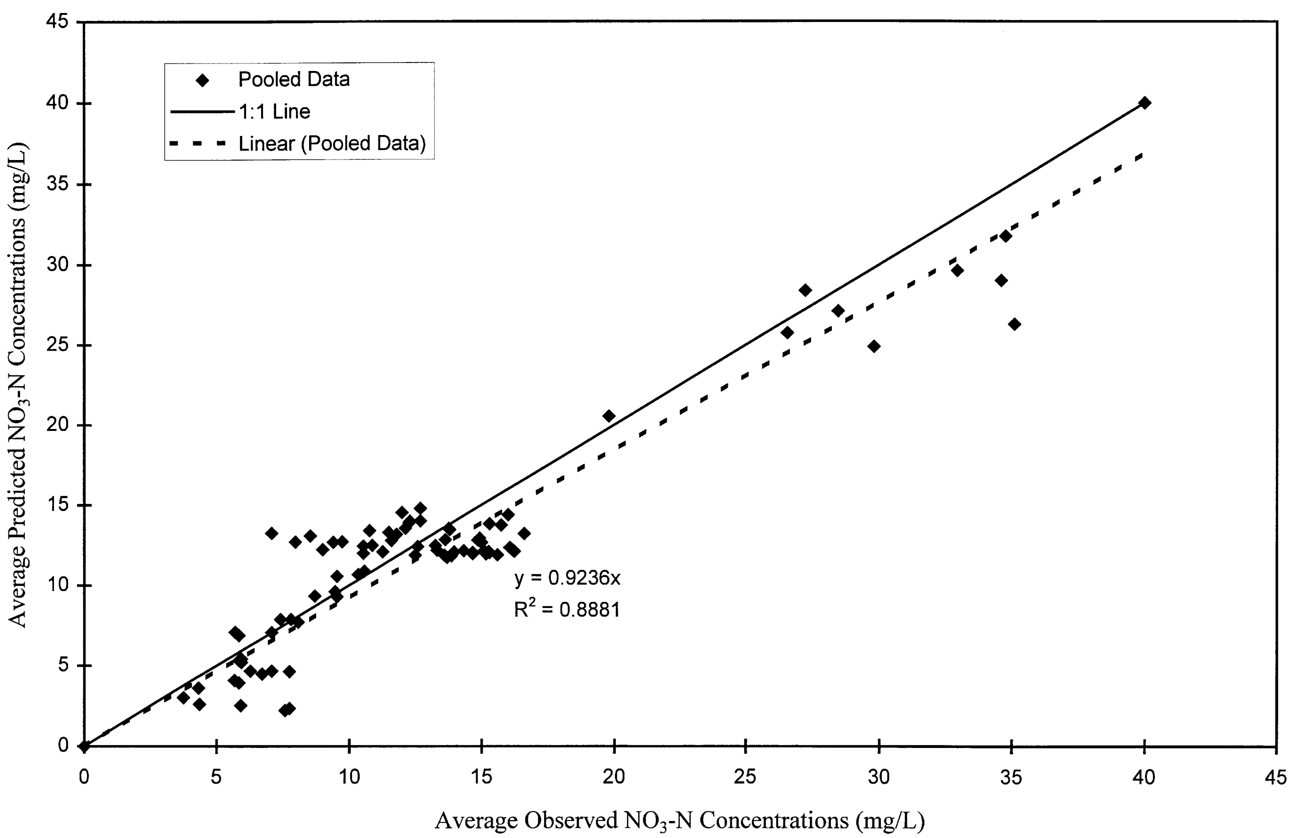


Figure 7–Best fit line for pooled observed and predicted NO_3-N concentrations in subsurface drain water for 1993 and 1995 (average of three plots).

with interception equal to zero was 0.92 (smaller than 1.0 – slope of 1:1 line), indicating underestimation of NO_3-N concentrations in subsurface drain water. However, the slope of the best fit line was not significantly different from 1. A careful visual observation of the best fit line for the pooled data (fig. 7) revealed that few points (nitrate peaks) at the end of the best fit line dominate the slope of the best fit line. Otherwise, the best fit line passing through rest of the data (excluding few points on the extreme left) provided a slope much closer to the 1:1 line.

Soil Profile NO_3-N Contents

Figure 8 shows measured and predicted total NO_3-N in the 0-1.2 m soil profile for the three plots (average of three plots) during the 1993 and 1995 growing seasons. The linear regression (zero interception) between observed and predicted soil profile NO_3-N values gives R^2 of 0.98 with a slope of 0.99 which is not significantly different from 1 (at 0.05 significance level). The RZWQM predicted higher soil profile NO_3-N in 1995 compared to 1993. Again, the reason for this was a higher amount of N application with manure during 1995 growing season. Also, the year 1994 was a dry year and due to less leaching during the growing season, NO_3-N accumulated in the soil profile.

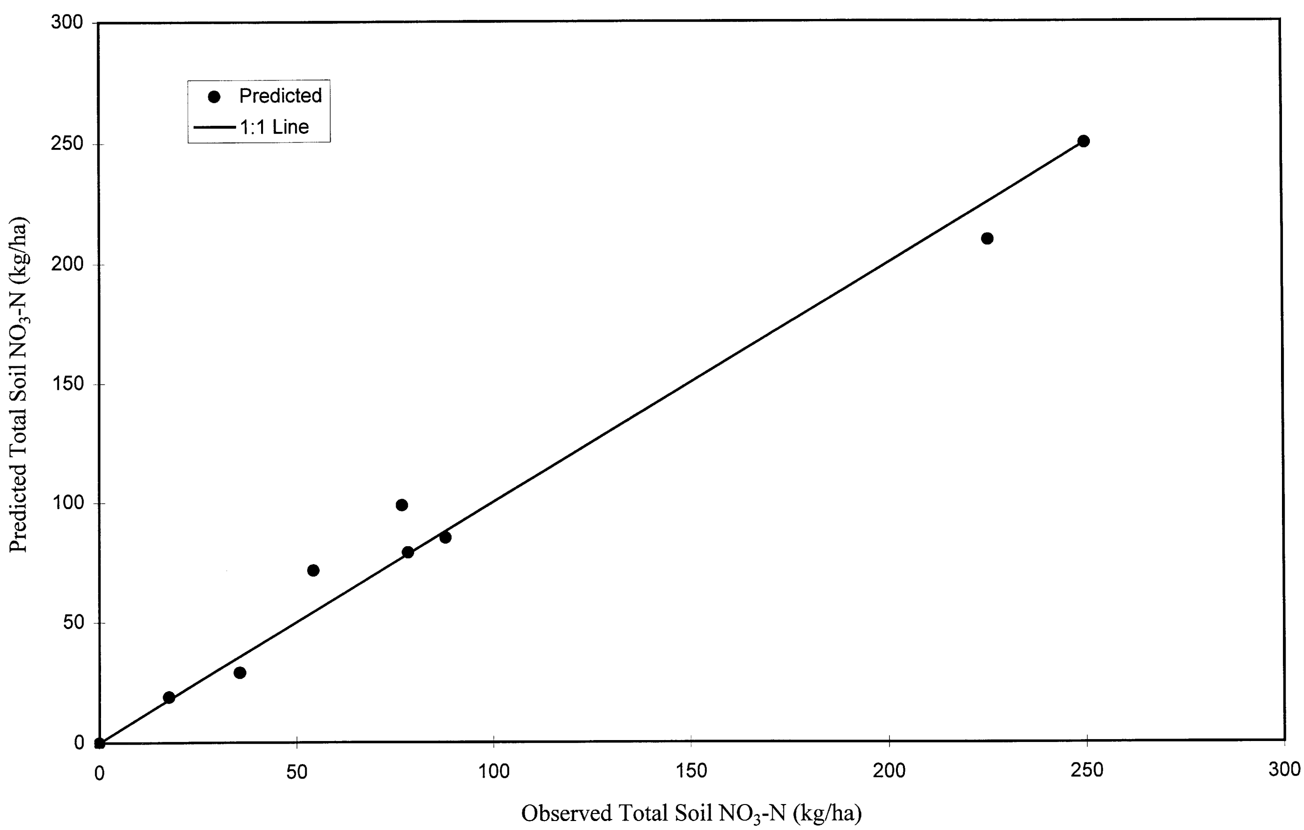
Considering various factors that influence the field data such as human error and spatial variability in soil properties, the overall results of this study indicate that the RZWQM has the capability of simulating the effects of manure application on subsurface drainage water quality from an agricultural field under different soil and weather conditions.

Summary and Conclusions

The RZWQM was calibrated and evaluated for simulating subsurface drain flows and NO_3-N concentrations in the subsurface drain water and in the soil profile as affected by manure applications on a field under continuous corn production in Iowa. The model was calibrated using field data from the year 1993, then data from 1995 were used to evaluate the model. The model evaluation was performed comparing field observed subsurface drain flows, drainage water NO_3-N concentrations, and soil profile NO_3-N contents with the values predicted by the RZWQM.

Predicted subsurface drain flows for 1993 and 1995 compared reasonably well with measured flows. Peaks of the measured and predicted subsurface drain flows were not exactly the same at all times. Simulated seasonal subsurface drain flows were in close agreement with the observed values (overall percentage difference being within +3.1% and –10.9% for 1993 and 1995, respectively).

The predicted NO_3-N concentrations in subsurface drain flows generally followed the observed trends with few exceptions. Annual average NO_3-N concentrations in subsurface drain water for 1993 and 1995 were close to the observed values. Comparison of NO_3-N concentrations between observed and predicted data (average of three plots for two years) on 1:1 basis revealed that model predictions were satisfactory. Predicted total NO_3-N contents in the 0 to 1.2 m soil profile were also in close agreement with the observed values. Discrepancies between predicted and observed NO_3-N concentrations indicated a need for better estimation of various rate coefficients and organic matter pools. Without a proper freeze/thaw component, the



RZWQM fails to simulate an accurate water table depth in the field during continuous simulations. Modifications are needed in the hydrology component of the RZWQM to correctly estimate water table depths in the months of March/April during continuous simulations. The overall results of this study indicate that the RZWQM has the potential of simulating the effect of manure applications on water quality for Iowa soils.

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